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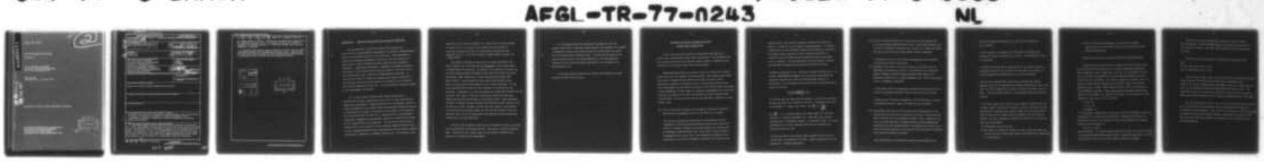

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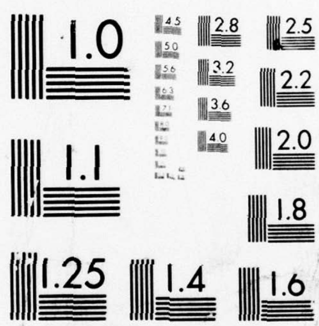

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SPACE INTERACTION STUDY

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Final Report
1 October 1976 - 1 October 1977

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Spacecraft interaction with environment. Satellite wake. Angular distribution of thermal ions. Satellite potential. Charging mechanisms. In-situ measurements. Parametric investigation. Electron temperature and density. Plasma perturbations.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A preliminary examination was conducted with the objective of evaluating some in-situ measurements obtained from the S3-2 and S3-3 Satellite for the study of the interaction between an ionospheric satellite and its environmental space-plasma. Specifically, we refer to the measurements of ion currents, electron density and temperature, ionic composition, space potential and electric fields and examine their use for the study of the angular distribution of ions around the satellites. The distribution is investigated versus the parameters:

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$R_D = \frac{Ro}{\lambda_D}$; $T = \frac{Te}{T+}$; $S = \frac{Vs}{V_T(+)}$; $\phi_N = \frac{e\phi s}{KT_e}$ **(where: Ro = radius of satellite, λ_D = Debye length, Te and T+ = electron and ion temperatures respectively, Vs = Satellite velocity, Vs(+) = ion thermal velocity, ϕs = satellite potential, K = Boltzman constant, e = electronic charge) which vary with ionospheric conditions.**

It was found that selected passes traversed by the S3-2 and S3-3 satellites should provide for an interesting and useful study. Results from the study could also be utilized for the planning phase and data-analysis of experiments mounted on board the shuttle-spacelab platform.

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Introduction:- Objectives of study and brief scientific background.

The main objective of the study titled; "The interaction of a spacecraft with its environmental spaceplasma" is to perform a phenomenological study of some problems involved in this interaction. The investigation is conducted by analyzing measurements of electrons, ions and potentials (or; local electric fields) performed by probes mounted on board atmospheric - ionospheric - magnetospheric satellites, attempting to determine the spatial distribution of the charged particles and the potential in the near vicinity of the spacecrafts, under a variety of plasma parameter conditions. In particular the effort is focused on determining the spatial distribution of electrons ions and local electric fields (or; potential) in the vicinity of the Air Force satellites S3-2 and S3-3. For that purpose the already available in-situ measurements are utilized.

As it is well known, any kind of body moving hypersonically or supersonically through a spaceplasma interact with it, hence producing very significant perturbations. These perturbations (or; disturbances) consist of a wake zone behind the body possible shock waves ahead and behind the body and a redistribution of charge (or: potential) on the surface of the spacecraft. The interaction between the body (e.g. a spacecraft) and its environmental spaceplasma is mutual hence the phenomena involved are coupled by the effects on the spaceplasma and on the spacecraft. The spacecraft itself acquires a potential due to the collection of the surrounding charged particles and due to other charging mechanisms such as photoemission, particle emission, magnetic field effects, bombarments of energetic particles etc. If the surface of the

spacecraft is not a perfect conductor i.e. $\Sigma i(T) \neq 0$ over the whole surface but rather $\Sigma i(T) = 0$ at points on the surface than effects known as "spacecraft charging" may occur, and under special conditions be very significant (see e.g. "Spacecraft charging by Magnetospheric Plasmas", ed: A. Rosen, 1976).

The plasma surrounding the spacecraft is strongly perturbed by the latter's motion, and a wake zone, depleted unequally of ions and electrons, is formed behind the spacecraft. In addition to the creation of the wake, the spacecraft excites plasma oscillations in the electrostatic mode (e.g. Samir and Willmore, 1965: Gurevich et al, 1969, Gurevich and Pitaevsky, 1975: Alpert, 1976). A potential-well (in some cases, potential-wells) forms behind the spacecraft at some distance from its surface downstream. In some cases potential-wells can form in other locations in the vicinity of the spacecraft. Furthermore, it can be anticipated (Liu, 1969: 1975 (a,b) Gurevich and Pitaevsky, 1975: Alpert, 1976) that wave-particle interactions take place between the particles and the waves in the potential wells. Some experimental "evidence" to support the above was given and discussed by Samir and Wrenn 1972; and Troy et al. 1975. Moreover, the fact that there exists a steep gradient in electron and ion deusities between the wake zone and elsewhere around the spacecraft give rise to the speculation that some kind of plasma instability should exist in the disturbed zones.

From the above discussion follows that the interaction between a spacecraft and its environmental spaceplasma includes a wide spectra of complex phenomena some of which may have a severe impact on the validity, reliability and quality of low energy in-situ measurements.

It is anticipated that the investigation as proposed in the 1976 proposal should help in achieving a better physical understanding of the complex of phenomena involved in the interaction as well as help assess the quality of in-situ observation as mentioned above. It should also be realized that the more applied aspect of the study should help in the development and planning of future active and passive experiments to be performed in the Spacelab-Shuttle era.

In the next section we will discuss briefly the preliminary work done through the 1976/7 contract period.

Discussion of activity throughout the period

October 1970 to October 1977.

In this section we discuss briefly the preliminary work done over a period of 12 months between October 1976 to October 1977. The preliminary work done provides the basis for the continued research effort, as discussed in the Introduction of the present Report and the 1976 proposal.

Several discussions with the scientific staff of the Electrical Processes Branch (chief: Dr. R.C. Sagalyn) took place at AFGL. They focused on the optimal utilization of charged particle (electrons and ions) and electric field measurements available in the Branch in order to study various aspects of the interaction between the S3-2 and 53-3 satellites in the altitude range from perigee to about 800-900 km. We have looked at the general configuration of the satellites including the location of the probes and examined the useful information that can be obtained. The latter will be further discussed below, together with other relevant items.

(1). The ion current (i_+) variation with the angle of attack (θ) and with the angle between the geomagnetic field and the normals to the probes.

Here we are concerned with the utilization of measurements from the "experiment for directly measuring plasma bulk motions from a satellite" (Peter J.L. Wildman, "Studies of Law-Energy Plasma Motion: Results and a New Technique", AFGL-TR-76-0168, 25th of June 1976), and will attempt to investigate the ion current flow to the ion-probe as a function of the orientation to the velocity and magnetic vector for each rotation of the

satellite under a wide range of altitudes, latitudes local times etc. Namely, as a function of a wide range of plasma parameters. It should be realized that the term "ion-probe" refers (in this report) to an array of four planar sensors which act as current collectors and which are located in front and behind the spin-stabilized satellite (see: Report by P.J.L. Wildman). The above mentioned ion probe provides a technique for measuring the magnitude and direction of the bulk ion motion.

Preliminary inspection of $i_+ = f(\theta)$ plots at perigee altitudes and in the altitude range 600-800 km suggest that it is not yet clear whether the information available will cover the desired maximum range for θ. Nevertheless, it is anticipated that we will be able to obtain sufficient values for the ratio

$$\alpha\left(\equiv\left[\frac{i + (\text{wake})}{i + (\text{front})}\right]\right) = f(\theta_i),$$

for the wake and front zones and for altitudes for which such information does not yet exist in the scientific literature. We should also be able to investigate $\alpha = f(R_D, S, \phi_N)$ where: $R_D = \dfrac{Ro}{\lambda_D}$: $S = \dfrac{Vs}{\sqrt{\dfrac{2KTe}{M+}}}$

$\phi_N = \dfrac{e\phi s}{KTe}$, Ro = satellite radius, λ_D = Debye length, V_s = satellite velocity, Te = electron temperature, $M+$ = ionic mass, ϕ_s = satellite potential and K = Boltzmann's constant, e = electronic charge. The latter investigation is of utmost importance both from the scientific and application points of view.

In the first phase of the study we limit ourselves to the use of low latitude data i.e. $|\text{latitude}| \lesssim (30^0\text{-}40^0)$. Hereby avoiding the use of an unquiet and disturbed spaceplasma.

(2). In order to obtain the values of Te Ne and ϕ_s we use measurements made by the boom mounted spherical electron probe. These plasma properties are required for defining the parameters R_D, S and ϕ_N. It is also anticipated that the electron data will provide ambient electron information.

It appears that one set of Te, Ne and ϕ_s measurements can be obtained for every three satellite spin cycles.

(3). Knowledge of the values of M+ will be required for defining S and for examining the variations of α with M+. The idea here is to investigate whether α depends on specific plasma properties rather than on non-dimensional quantities (i.e. plasma parameters) only. Such an investigation will be of fundamental importance.

At the present time we are beginning to require data from selected orbits but the actual physical analysis using the latter has not yet started.

It will also be of interest to examine $\underline{\alpha} = f(\theta)$ variations for a variety of [Te(ambient)] values. Again, this study had not yet started.

(4). The proposed study calls for the extensive use of measurements from the E-field probes both from the 27 m and the 11 m sets i.e. for the positions where the dipoles were fully deployed in flight. Also, it might turn out to be of extreme importance to examine $\underline{E}$-fields and other superimposed information from the undeployed dipole. The analysis of the latter could reveal interesting features in the vicinity of the S3-2 and S3-3 satellites which were never explored in the past.

Only recently have we received some relevent data from AFGL and the

writing of computer codes needed in the process of the analysis is now in progress.

We have examined a few samples of the data sent to us recently and assessed the "order of reliability" of the data. This feasibility study is in progress.

It should be realized that for the purposes of the present study where averaging processes may not in general be very useful, the selection of the most adequate and reliable data is of critical importance.

We have by now overcome some difficulties in matching the required Ephemeris data with the appropriate and relevant measurements. Work on the latter is still in progress but we hope to conclude this effort very soon Then the data becomes available (in the desired format) for scientific analysis.

As the final stage of data format we need ephemeris information such as: altitude, magnetic latitude and longitude, local time, universal time and specification of sunlight and/or shadow together with the corresponding angle of attack and the angle between the magnetic field and the probe normals. The above information is required for each set of ion, electron and E-field measurements.

The measurements required are the:

(1) ion current or density (if possible) for each of the four sensors in the two array sets, namely eight values of [i(ions)] and/or combinations of current ratios.

(2) electron density and temperatures to provide for the ambient conditions as well as the values of ϕ_s as derived from the current-voltage characteristics.

(3) $\underline{E}$-fields from both the fully deployed and the undeployed dipoles.

During the period of October 1976 to October 1977 we were also involved in the modification and testing of the L.W. Parker wake/sheath theoretical model attempting to make it applicable to the case of an ionospheric satellite with the objective of applying it to the data (discussed above) of the S3-2 and S3-3 Air Force Satellites. The extensive program is now almost ready to be applied to bodies such as cylinders and for specific ranges for the plasma parameters: R_D, S, and ϕ_N. These ranges cover part of what is encountered by real ionospheric satellites. These ranges should be extended with particular emphasis on the parameter R_D. Recently, the program is in the process of being employed for real cases i.e. for the ranges:

$1 \leq R_D \leq 9.5$

$1.1 \leq S \leq 3.7$

$3.8 \leq |\phi_N| \leq 5.7$

It is reasonable to assume that at least part of the above paramatric ranges will be applicable to the S3-2 and S3-3 satellites. Unexpected difficulties, in particular in as far as the influence of the iteration number of the complex solution on the structure of:

$Ni, Ne, \phi = f(r,\theta)$

were encountered. Our present findings already throw light on the practical value of using various theoretical models in theory - experiment comparissons. No final and conclusive results has yet been reached and work is in progress.

The theoretical model mentioned above attempts to solve the Vlasov - Poisson equations in a self-consistent manner by following trajectories from the satellite to infinity. The difficulties involved in such a treatment are well known.

Finally, we should restate that the objectives of the study are tow-fold:

(i) the basic science point of view.

(ii) the application point of view.

From the 'basic science' point of view, the study of the interaction between the S3-2 and the S3-3 satellites with their natural environment should contibute to the better understanding of phenomena involved (in the more general sense) in the interaction between rarefield plasmas and bodies in space. The measurements used in the study should enable the testing of various theoretical models, hence help assissing the value of physical assumptions used in the models.

From the 'applications' point of view, the study of the perturbations created due to the satellite motion should help assess the reliability and quality of low-energy in-situ measurements. Such a study is also relevant to the investigations of phenomena involved in spacecraft-charging. Furthermore, such studies should pave the way for the better planning of measurements to be performed on board the Shuttle/Spacelab.

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